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TECHNICAL REPORT NO. 18

AN EXPERIMENTAL STEEL – FIBER – REINFORCED CONCRETE BRIDGE DECK OVERLAY

materials bureau technical services subdivision

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AN EXPERIMENTAL STEEL-FIBER-REINFORCED CONCRETE BRIDGE DECK OVERLAY

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MATERIALS BUREAU
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ABSTRACT

To gain first-hand experience in the use of fibrous (steel-fiber-reinforced) concrete, in 1973 the Materials Bureau of the New York State Department of Transportation instituted a limited experimental project, consisting of four phases -- laboratory work, trial plant batching, construction of a bridge deck overlay, and post-construction inspections. The results to date indicate that construction placement techniques similar to those for normal portland cement concrete can be used, but that the material is expensive on a first-cost basis. Time-consuming batching is a drawback and proper fibers, free from drawing compounds, must be used to achieve desired strength results. Performance of the bridge deck overlay has been disappointing. Fifteen cracks apparently related to shrinkage have formed, and 50 spalls possibly related to fiber corrosion have occurred.

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INTRODUCTION

The Materials Bureau of the New York State Department of Transportation continually evaluates new construction materials, and is especially interested in those promising more economical and better performing transportation systems. Thus, over the past few years, the Bureau has followed the development of fiber-reinforced concrete with interest. Research elsewhere indicates that this material may be superior to plain or reinforced concretes. To gain experience with it, in 1973 the Department instituted a limited experimental project using steel-fiber-reinforced or "fibrous" portland cement concrete to reconstruct a bridge deck.

Fibrous concrete is a composite material composed of conventional portland cement concrete materials with steel fibers randomly dispersed throughout the concrete mass. They are intended to act as arrestors, restricting the growth of flaws in the concrete matrix and preventing their enlargement under stress into cracks that could cause failure.

The intended purposes of this experimental project are fourfold:

1. To evaluate long-term performance of fibrous concrete when used in a bridge deck overlay pavement ("performance" in this instance is considered resistance to spalling, crack propagation, wear, freeze-thaw cycles, and chemical attack),

2. To evaluate costs and economics of fibrous concrete,

3. To assess current methods of manufacturing, handling, and working with fibrous concrete and its components, and

4. To compare laboratory performance of fibrous concrete with that of more conventional concretes.

To accomplish these purposes, the project was broken into four phases -- laboratory work, trial batching, construction work, and post-construction inspection.

TABLE 1. MIX PROPORTIONS PER CUBIC YARD.

Quantity or Test	Fibrous Concrete	NYSDOT Class A Concrete	8-Bag Concrete	8-Bag Mortar
Portland Cement (Type II), lb	752	587	752	752
Fine Aggregate, lb (Saturated Surface Dry) (Fineness Modulus = 2.9)	1870	1033	1090	1870
Coarse Aggregate, lb (Saturated Surface Dry)	610[a]	1985[b]	1680[b]	610[a]
Steel Fibers, lb ($2\frac{1}{2}$ x 0.025 in.)	150	--	--	--
Water, lb	368	276	300	368
Air, percent	7±2	6±2	6±2	7±2
Slump, in.	3 to 6	$1\frac{1}{2}$ to 3	$1\frac{1}{2}$ to 3	--

[a]No. 1 size.

[b]Nos. 1 and 2 sizes.

TABLE 2. COARSE AGGREGATE GRADATION LIMITS.

Screen Size, in.	Percent Passing by Weight: Size No. 1	Size No. 2	Nos. 1 & 2 Combined
$1\frac{1}{2}$	--	100	100
1	100	90-100	93-100
$\frac{1}{2}$	90-100	0-15	27-58
$\frac{1}{4}$	0-15	--	0-8

I. LABORATORY WORK

Laboratory study was originally undertaken to check workability of the mix design in the Department's specification for Item 47F (Concrete Pavement -- Steel Fiber-Reinforced), given here in Appendix A. This specification was developed especially for the experimental fibrous concrete bridge deck overlay to be placed as part of this investigation. Checking workability provided an excellent opportunity to run small-scale comparison tests between fibrous concrete and several conventional concrete mixes.

In the laboratory test program, in addition to the fibrous concrete, three other mixes were batched and tested:

1. NYSDOT Class A concrete,

2. An eight-bag mix that was actually the fibrous concrete mix with the fibers omitted (for identification purposes in this report, this mix is referred to as an eight-bag mortar mix), and

3. An eight-bag concrete mix.

Table 1 gives the desired proportions of these mixtures; slump and air were monitored during laboratory work and were within the ranges listed. Table 2 gives the general gradation limits of the coarse aggregate used.

The specified fibrous concrete mix design was recommended by the Battelle Development Corporation. The fibers used were supplied by the Atlantic Wire Company, a Battelle licensee. The steel fibers were 2½ in. long by 0.025-in. diam. They were copper in color, except for shiny steel-gray ends. Atlantic Wire indicated that the copper coloring was due to the drawing compound used in manufacturing the fibers. Both Atlantic Wire and Battelle maintained that this fiber type had been used previously and had not caused detrimental effects.

NYSDOT Class A concrete is a 6¼-bag/yd^3 mix, intended for use in structures; it is the normal class of concrete for bridge deck overlay pavement. In overlays it is used with steel reinforcing mesh, but it was believed that a comparison between Class A and fibrous concretes could be valuable. Further, since fibrous concrete contains eight bags of cement per cubic yard, a comparison with a well-designed eight-bag concrete mix also might be valuable. Finally, to determine the effect of the steel fibers, the fibrous concrete mix without the fibers was tested.

Flexural beams and compression cylinders were cast and cured for seven days according to ASTM C 192. Flexural strength testing was conducted in accordance

TABLE 3. SUMMARY OF STRENGTH TESTS*.

Material Tested	7-Day Ultimate Flexural Strength, psi	7-Day Compressive Strength, psi
Fibrous Concrete	$\bar{x}$ = 630	$\bar{x}$ = 3300
	s = 76	s = 453
	n = 3	n = 6
NYSDOT Class A Concrete	$\bar{x}$ = 490	$\bar{x}$ = 2600
	s = 70	s = 369
	n = 3	n = 5
8-Bag Concrete	$\bar{x}$ = 660	$\bar{x}$ = 4000
	s = 28	s = 218
	n = 3	n = 3
8-Bag Mortar	$\bar{x}$ = 540	$\bar{x}$ = 3030
	s = 53	s = 286
	n = 3	n = 6

*$\bar{x}$ = mean strength
s = standard deviation
n = number of samples

TABLE 4. FREEZE-THAW TESTING OF 14-DAY-OLD SAMPLES.

Material Tested	Weight Loss, percent	
Fibrous Concrete		
Sample 1	5.5	
Sample 2	4.6	
Sample 3	6.5	
Average		5.5
Class A Concrete		
Sample 1	3.6	
Sample 2	3.9	
Sample 3	4.1	
Average		3.9
8-Bag Mortar		
Sample 1	5.3	
Sample 2	5.2	
Sample 3	5.5	
Average		5.3

with ASTM C 78, while compressive strength testing was in accord with ASTM C 39. Results of the strength testing are given in Table 3. Surprisingly, the eight-bag concrete mix provided higher strength in both flexure and compression than the fibrous concrete.

Three 3- by 4- by 8-in. prisms of Class A, fibrous, and mortar mixtures were prepared and tested for resistance to freezing and thawing. All nine prisms were placed in a 10-percent by weight sodium chloride solution and subjected to 25 cycles of freezing and thawing. Temperatures ranged each day from 10 F ± 2 deg for 16 hours to 70 F ± 5 deg for 8 hours. Table 4 gives the average percent loss of weight resulting from this testing. Here the results are also surprising. The fibrous concrete did not perform as well as either the Class A concrete or the eight-bag mortar.

TABLE 5. TRIAL BATCH DATA.

Test	Batch 1	Batch 2	Batch 3
Slump, in.	6½	3¼	3½
Air, percent	10.0	6.8	3.0
Unit Weight, pcf	131	137	144
Ultimate Flexural Strength, psi			
7-Day	315	465	380
14-Day	--	--	515
28-Day	470	640	560
Compressive Strength, psi			
7-Day	1700	2835	2325
14-Day	--	--	2845
28-Day	2715	3870	3355

II. TRIAL BATCHING

Trial batching was required by the specification. The purposes were 1) to develop methods of charging the mixer and of mixing, 2) to check the workability of the fibrous concrete produced for the job, and 3) to gain experience in handling and finishing fibrous concrete. Trial batching also afforded an opportunity to conduct additional physical testing. It was scheduled for October 2, 1973. On October 1, Battelle informed the Materials Bureau that they had experienced shrinkage cracking problems with the fibrous concrete mix design they had previously recommended. That mix design had been incorporated into the specification. To overcome the shrinkage problem, Battelle recommended the following new mix:

Portland Cement, Type II	600 lb
Fine Aggregate, saturated surface dry	1450 lb
Coarse Aggregate, saturated surface dry	1450 lb
Steel Fibers, 2½ by 0.025 in.	100 lb
Water	300 lb
Air	7 ± 2 percent
Slump	3 to 5 in.

On October 2, three 1-yd^3 fibrous concrete trial batches were produced by Miron Concrete at their Kingston, New York plant. The first two batches were the specification mix. The third was that recommended by Battelle on October 1.

The procedure developed and used to charge the 8-yd^3 transit-mix trucks was to load the fine and coarse aggregates and 70 percent of the mix water. The fibers were then added while the drum rotated at mixing speed (6 to 12 rpm). After introducing the fibers, the cement and remaining water were added. The ingredients were mixed for 70 revolutions. During trial batching, the fibers were added by hand. Both the state and the producer realized that hand introduction of the fibers would be time-consuming and thus impractical during construction. For construction production, the producer would set up a method of introducing the fibers using a vibrating grate.

The first 1-yd^3 trial batch had a high slump and was obviously wet. It was speculated that the wet mix resulted from leftover wash water in the 8-yd^3 transit-mix truck. Less water was added to the second batch and slump was within the specification limits. The third batch was the new mix design, had low air content, and contained a few fiber balls. All three batches were sampled for slump, air, unit weight, and compressive and flexural strengths. Table 5 gives results of these measurements. The strength specimens were covered and allowed to cure for one day at the batch plant, and then transported by truck to Albany for further curing in a fog room at 100-percent relative humidity and 73 F ± 3 deg.

Workability, handling, and finishing characteristics of the fibrous concrete batches were checked by state personnel. All three batches produced workable, readily finished material. No handling problems were encountered and normal concrete tools were used.

III. CONSTRUCTION WORK

The bridge selected had the following contract description:

Bridge No. 2
Over the Roeliff Jansen Kill
Rhinebeck-Hudson, Part 4
N.Y.S. Route 9G, S.H. #8359
Columbia County
Contract No. RCR 73-85
Project Identification No. 8001.12

The structure is a four-span deck truss built in 1932, with a total length of 363 ft and a curb-to-curb width of 30 ft, providing two lanes of traffic. It also has a 5-ft sidewalk on one side. The longest span is 140 ft. The existing deck in 1972, when the Materials Bureau conducted a routine evaluation of structural condition, consisted of a 2-in. ± bituminous concrete surface overlaying a 4-in. portland cement concrete wearing slab and a 12-in ± structural concrete slab. The bridge was built with a bituminous membrane between the concrete wearing and structural slabs. The 1972 average daily traffic was 2300 vehicles, of which 7 percent were trucks.

Before reconstruction (Fig. 1), the bituminous overlay was cracked and spalled at both expansion joints. There was also a large patched area in the northbound lane and bituminous cracking and spalling had occurred at the structure's transverse joints. Further, there were hollow soundings approximately 3-ft from each curb throughout the full length of the bridge. An inspection of the underside of the deck showed two staggered longitudinal cracks running the entire length of the bridge deck. Coring revealed that the original concrete wearing slab was in very poor condition -- it was badly cracked and in some areas reduced to rubble. Aside from the longitudinal cracking, the structural concrete slab, however, was in good condition, as were the abutments and piers. The sidewalk and curbs had experienced some spalling and scaling, but generally they too were in good condition.

To rehabilitate the deck and riding surface, it was decided to remove both the bituminous overlay and the concrete wearing slab. A new 4-in. fibrous concrete wearing slab would then be constructed over the structural slab. There would be no attempt to bond the fibrous concrete to the structural deck, but none to prevent the bond either. Thus, a partially bonded overlay would be created. Also, no rigid repair would be made to the longitudinal cracks in the structural slab, since cracking would probably occur again in the same general locations. The cracks would be sealed, however, with a hot-poured rubber asphalt or a two-part polyurethane compound (Appendix B); the option as to which material to use would be given to the contractor.

Figure 1. Before removal of existing bituminous overlay, one-way traffic control was established (A); old overlay had patches at armored joint over center pier (B); longitudinal cracks on underside of structural slab (C) ran the bridge's entire length; core from southbound lane (D) displayed, from left, 2½-in. bituminous overlay, 2-in. of rubble from concrete wearing slab, 1½-in. concrete section with horizontal cracks also from wearing slab, bituminous membrane, and 7-in. of solid, crack-free structural slab.

In the following discussion, it should be borne in mind that both the contractor, J. J. Keenan, Inc., and the producer, Miron Concrete Inc., were working under an experimental specification, using an unfamiliar material and unfamiliar techniques.

Figures 2 and 3 show construction techniques and Table 6 gives field data and the results of fibrous concrete strength tests. (The strength specimens were cured and transported to Albany in the same manner as when trial batching.) By late October 1973, the contractor had removed the bituminous overlay, the concrete wearing slab, and the bituminous membrane. He chose to seal the longitudinal cracks in the structural deck with polyurethane compound. He agreed to pave the northbound lane with the original fibrous concrete specification mix and the southbound lane with the modified mix recommended by Battelle on October 1. This would provide an opportunity to check the cracking problems Battelle had previously experienced. If cracking occurred, the new mix could be evaluated to see if it offered any advantages over the original mix design. The lanes were constructed one at a time so that traffic could be maintained on the structure.

The northbound lane was to be paved on October 24 with a 4-in. fibrous concrete overlay. Batching was planned to start at 7:30 a.m. so that placement could get underway at approximately 8:00 a.m. Evidently, there was a lack of organization at the batch plant. Charging of the first transit-mix truck did not start until shortly before 9:00 a.m. The producer's men did not use the vibrating grate they had built for fiber introduction, but instead added fibers by hand. Thus, it took approximately 1-3/4 hours to charge the first truck. This truck arrived on the job site at 11:00 a.m. Large balls of fibers were falling out of the back of the truck as it backed down the hill to the bridge deck. Besides balling, the concrete evidently had bulked. The entire 8-yd^3 of this truck were rejected.

This rejection, coupled with the unacceptable charging time, caused the producer to begin using the vibrating grate for fiber loading. By this time, a Battelle representative arrived at the batch plant and suggested using a table to spread out the fibers before running them through the vibrating grate and into the truck. He also suggested enlarging the grate openings and it seemed to work more effectively. These modifications were made while charging the second truck. Thus, it took approximately 1 hour to charge this truck with 8-yd^3 of fibrous concrete. It arrived at the bridge site at 12:30 p.m. Its load contained only two fiber balls and they were removed.

Batching was now becoming more organized and operating more smoothly -- the third truck was charged in about 12 minutes. No balls were found in this truckload when it arrived on the job. The fourth 8-yd^3 transit-mix truck was loaded with only 7 yd^3. This truck and all to follow were underloaded to avoid the bulking problem encountered with the first truck. No balls were found in the fourth truckload. The charging sequence was the same developed during trial batching -- the fine and coarse aggregate and 70 percent of the mix water were added to the truck while it was under the weight hopper. Then the fibers were added while the drum rotated at 6 to 12 rpm. After introducing the fibers, the cement and remainder of the water were added by the weight hopper. When

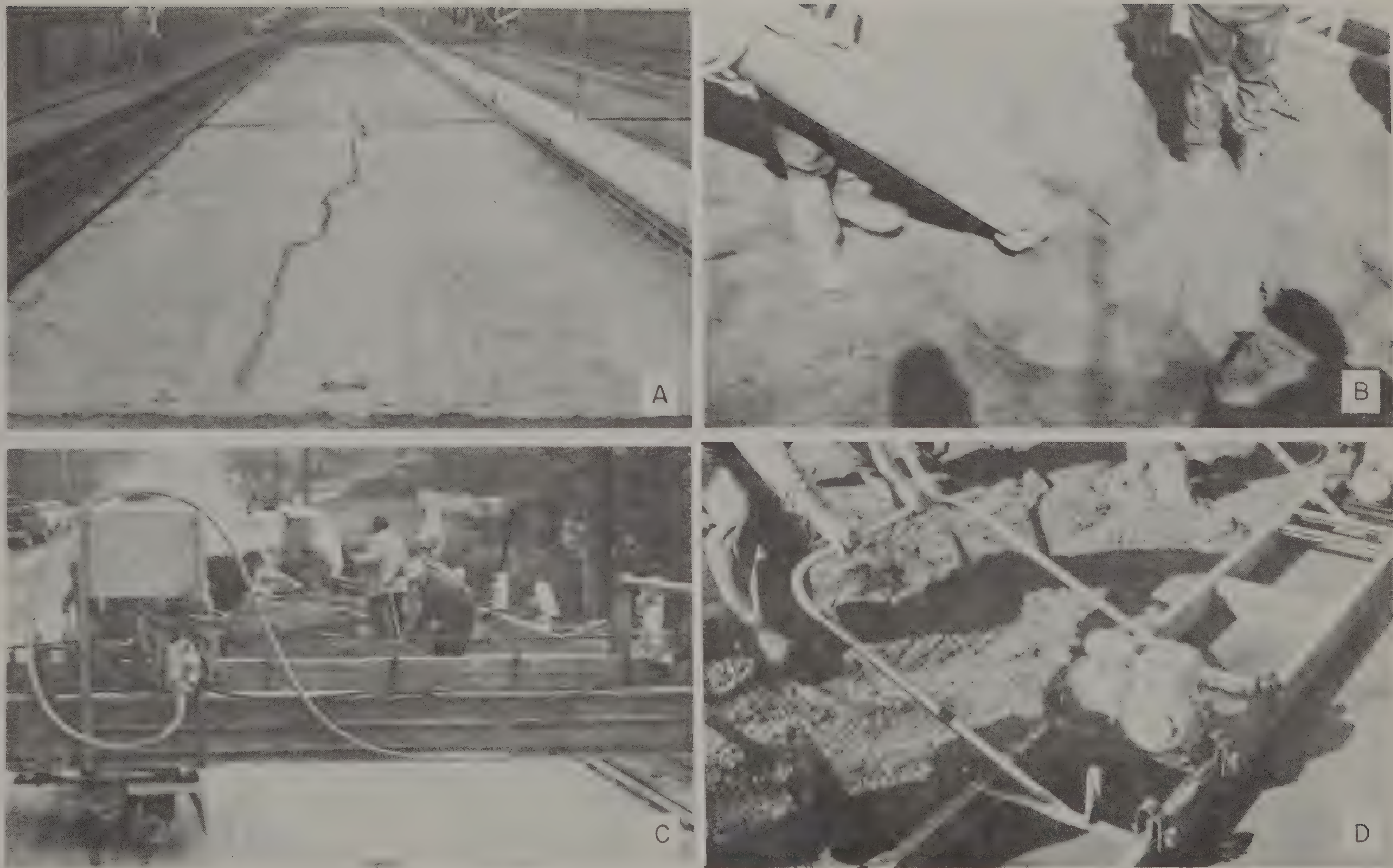


Figure 2. Before overlay application, the structural deck was exposed and cleaned, and longitudinal cracks were sealed (A); fibrous concrete was then placed on the wetted structural deck (B); use of a Borge finishing machine (C), too narrow for a 15-ft pour, was discontinued very early in construction; in its place the contractor substituted a homemade vibrating float (D) to finish the overlay, with good results.

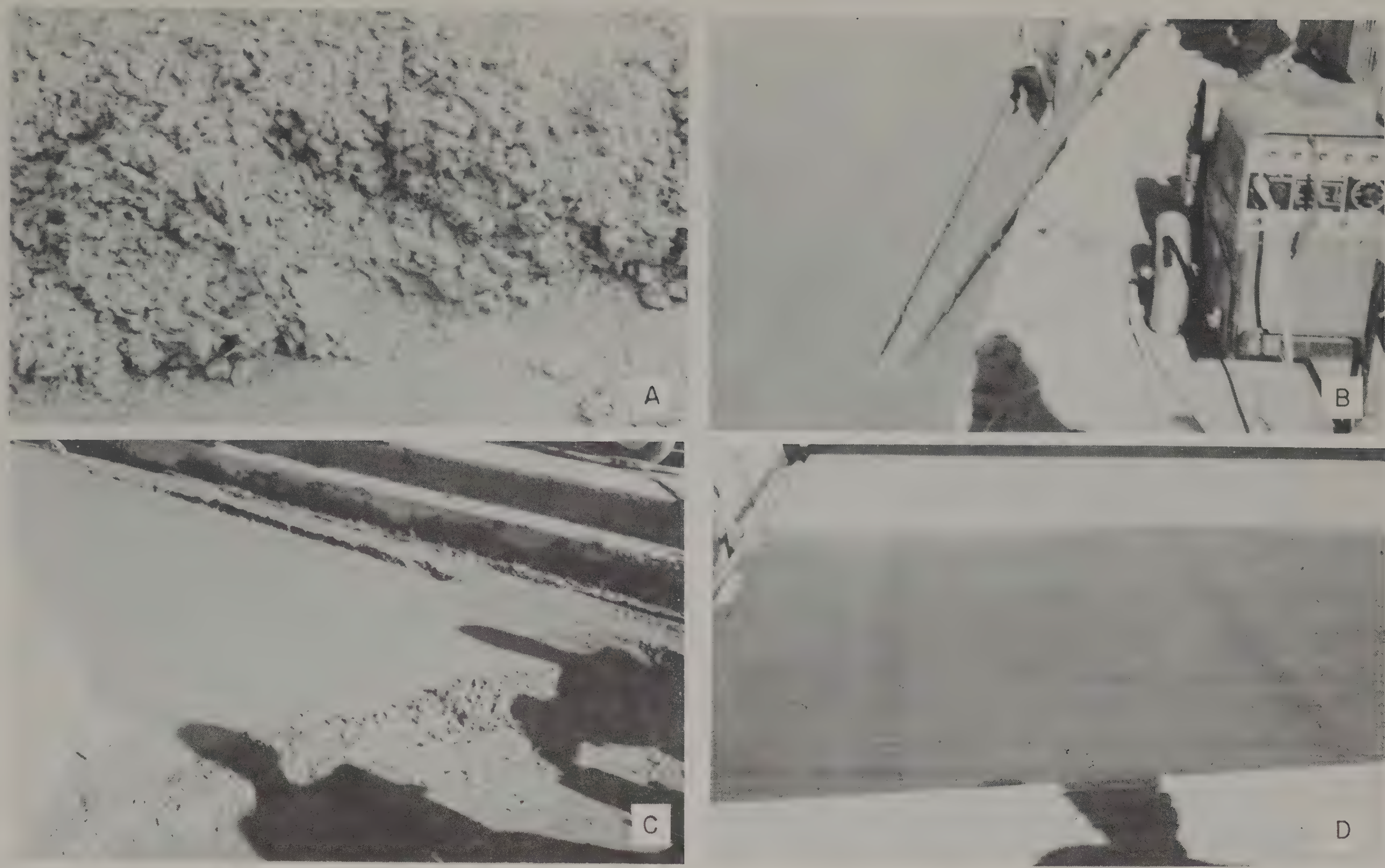


Figure 3. Steel fibers were visible (A) in the roll of concrete produced by the vibrating float; when the tracks the float rode on were removed (B), the resulting voids were filled in and finished (C); from the workers' bridge (bottom in D), visible are the broomed finish on the fresh concrete (center) and the pigmented curing compound being applied (top).

TABLE 6. SUMMARY OF DECK PLACEMENT.

Batch	Total Cu Yd	Truck	Plant Dispatch Time	Job Arrival Time	Mix Type[a]	Unit Weight, pcf	Slump, in.	Air Content, percent	Ultimate Compressive Strength, psi 7-day	Ultimate Compressive Strength, psi 14-day	Ultimate Compressive Strength, psi 28-day	Ultimate Flexural Strength, psi 7-day	Ultimate Flexural Strength, psi 14-day	Ultimate Flexural Strength, psi 28-day	Remarks
OCTOBER 24, 1973															
1	8	36	--	11:00 a.m.	1	--	--	--	--	--	--	--	--	--	Rejected; many large balls.
2	8	33	11:40 a.m.	12:30 p.m.	1	138	4-1/4	5.6	--	--	--	--	--	--	Used; only two balls.
3	8	32	1:25 p.m.	2:15 p.m.	1	140	3-1/4	6.8	3790	--	--	550	--	--	
4	7	36	2:25 p.m.	3:15 p.m.	1	141	3	5.5	--	--	--	--	--	--	
5	7	33	3:15 p.m.	4:00 p.m.	1	139	3-3/4	6.4	--	--	4480	--	--	572	
6	7	32	4:40 p.m.	5:32 p.m.	1	143	3-3/4	4.6	--	--	--	--	--	--	
OCTOBER 25, 1973															
7	7	32	9:55 a.m.	10:37 a.m.	1	143	2	5.0	--	3975	--	--	560	--	
8	8	38	10:50 a.m.	11:30 a.m.	1	138	4	7.2	--	--	--	--	--	--	10-yd^3 truck.
9	8	37	11:25 a.m.	12:00 a.m.	1	137	5-1/4	8.5	2330	--	--	420	--	--	10-yd^3 truck.
10	7	35	12:05 p.m.	12:45 p.m.	1	141	4-1/4	6.4	--	--	--	--	--	--	
11	7	25	12:35 p.m.	1:15 p.m.	1	138	4-1/2	7.2	--	--	4335[b]	--	--	580[b]	Only 4 yd^3 used.
NOVEMBER 15, 1973															
12	7	33	7:38 a.m.	8:25 a.m.	2	138	7	8.5	--	--	--	--	--	--	Rejected; wet mix containing many balls
13	7	32	8:01 a.m.	8:50 a.m.	2	140	4-1/2	7.4	--	--	--	--	--	--	Used; balls removed from mix
14	7	24	8:27 a.m.	9:15 a.m.	2	137	7-1/4	9.0	--	--	--	--	--	--	Rejected; wet mix containing balls
15	7	36	8:47 a.m.	9:40 a.m.	2	139	5-1/2	8.0	--	--	--	--	--	--	Used; balls removed from mix
16	7	33	10:08 a.m.	11:00 a.m.	2	142	4-3/4	6.0	2440[c]	--	--	390[c]	--	--	Used; mix contained some balls
17	8	23	11:34 a.m.	12:25 p.m.	3	135	6-3/4	10.0	--	--	--	--	--	--	Used; wet mix without balls; 10-yd^3 truck
18	7	36	11:53 a.m.	12:40 p.m.	3	139	5	7.6	--	3785	--	--	585	--	
19	7	34	1:16 p.m.	2:10 p.m.	3	138	3	8.0	--	--	--	--	--	--	
20	7	24	1:35 p.m.	2:20 p.m.	3	138	1-3/4	8.5	--	--	4505	--	--	665	
21	7	33	2:10 p.m.	3:00 p.m.	3	137	3-3/4	7.9	--	--	--	--	--	--	
22	8	23	2:38 p.m.	3:20 p.m.	3	138	2	8.0	--	--	4575	--	--	610	10-yd^3 truck
23	7	36	2:54 p.m.	3:40 p.m.	3	138	3-1/4	8.0	--	--	--	--	--	--	
24	2	24	4:00 p.m.	4:35 p.m.	3	--	4 est.	--	--	--	--	--	--	--	Only 1/2-yd^3 used

[a]Mix 1 (original 8-bag specification mix with 150 lb of steel fibers/yd^3) had an average water content of 415 lb/yd^3 and average water-cement ratio of 0.55.

Mix 2 (6¼-bag mix recommended Oct. 1 with 100 lb of fiber/yd^3) had an average water content of 366 lb/yd^3 and average water-cement ratio of 0.61.

Mix 3 (original 8-bag specification mix with fiber content reduced to 100 lb/yd^3) had an average water content of 338 lb/yd^3 and average water-cement ratio of 0.45.

[b]Cured 27 days.

[c]Cured 8 days.

the operation was running smoothly, four or five men needed about 10 minutes to add the fibers to a truck. Figure 4 shows the fiber introduction setup. They were emptied from their 50-lb cardboard boxes on to a sloping table, spread out, and raked down the table on to the grate, which was vibrated with a pencil vibrator to eliminate fiber balling.

With batching and charging problems under control, usable fibrous concrete started arriving on the job at a slow but steady pace. The slow pace was because the producer would not load a truck until he had word on whether the previous truckload had been accepted or rejected at the job site.

On the deck, the contractor attempted to use a Borge finishing machine for the overlay. This machine had a screw spreader, a roller, and a pan float, and was designed for 12-ft paving rather than 15-ft. Consequently concrete piled up at the edges of the lane. Its use was discontinued almost immediately, and the contractor then used a homemade vibrating float to finish the concrete. This worked well, producing a smooth surface that was later luted and broom-finished by hand. No finishing problems occurred after the initial trouble with the Borge machine. White membrane curing compound was applied to the overlay after brooming. The next day, after sawcutting the joints, Burlene blankets were placed on the overlay to protect it from cold weather.

Due to the late start and trouble at the batch plant, the contractor could complete only half the northbound lane that day. The work was stopped overnight at the armor joint over the middle pier. The next day (October 25) the second half of the northbound overlay was completed without problems.

The northbound lane was allowed to cure for the specified 15-day minimum before opening it to traffic, which was then wholly diverted to this lane as preparations began for paving the southbound lane. The entire southbound lane was overlaid on November 15, 1973, and some difficulties were encountered. This lane was to receive the mix recommended by Battelle on October 1. The first truckload of fibrous concrete, which arrived on the job at 8:25 a.m., was a wet load containing many fiber balls. It was rejected. The second truck arrived at 8:50; it too contained balls, but since slump and air were within specification limits, this load was used. The contractor was instructed to remove all balls from the deck. Two wheelbarrow loads were removed, probably representing 200 to 300 lb of fiber, or 1/3 to 1/2 the fibers in the truckload. The third, fourth, and fifth trucks to arrive on the job also contained balls. In addition to balling, the third truck had a wet load and was rejected. The fourth and fifth truckloads were used with the fiber balls removed. Figure 5 shows balls of fibers removed from the deck.

During the difficulties with the first five truckloads, it became obvious that some corrective action was necessary. The batch plant was apparently using the same loading technique that was successful on October 24 and 25, although one state engineer thought that during fiber introduction the truck drums were revolving more slowly than before. Several options were considered, including elimination of fibrous concrete and return to normal overlay practice. It was finally decided, however, to return to the original mix design used for the northbound lane, with fiber content reduced from 150 to 100 lb/yd^3. This decision was made because after rejection of the first truckload, the original

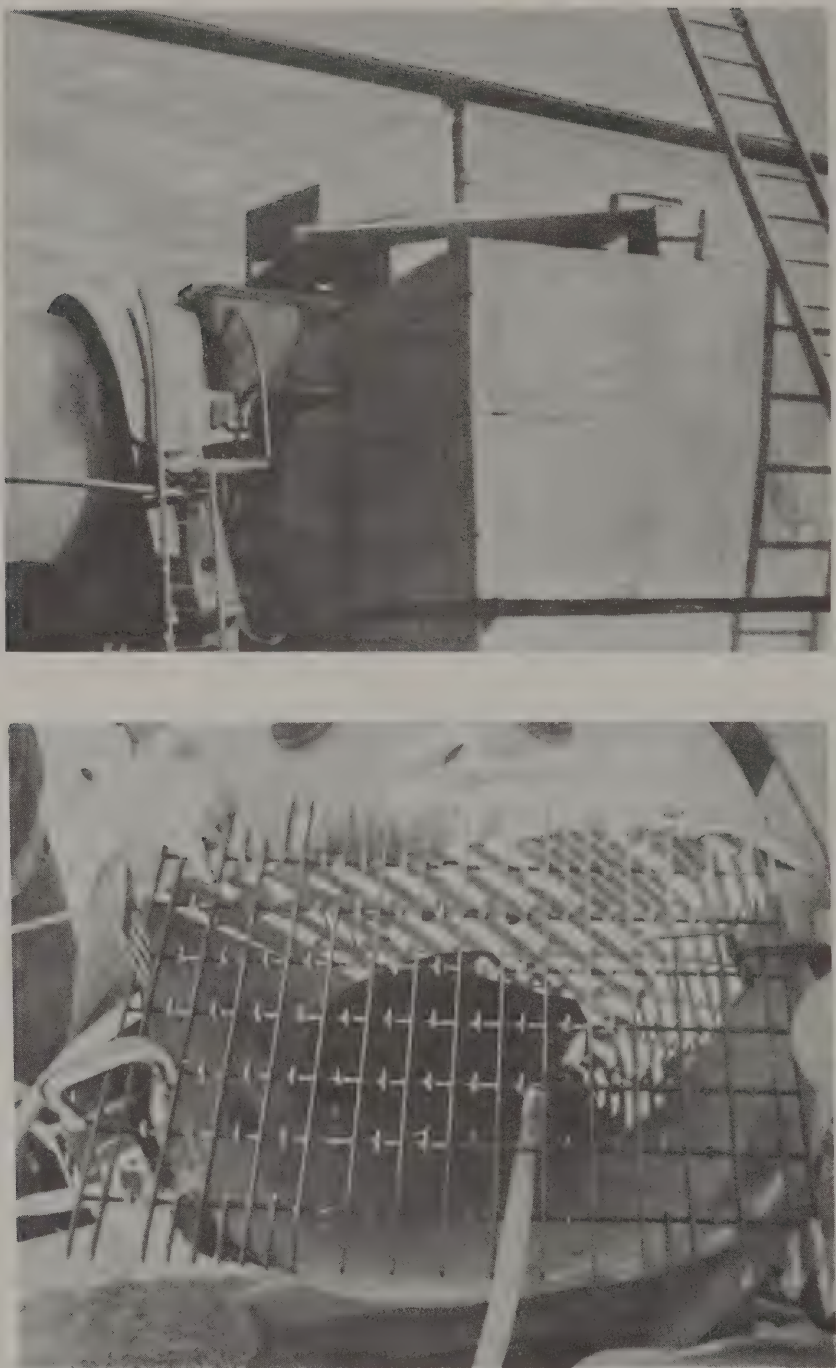


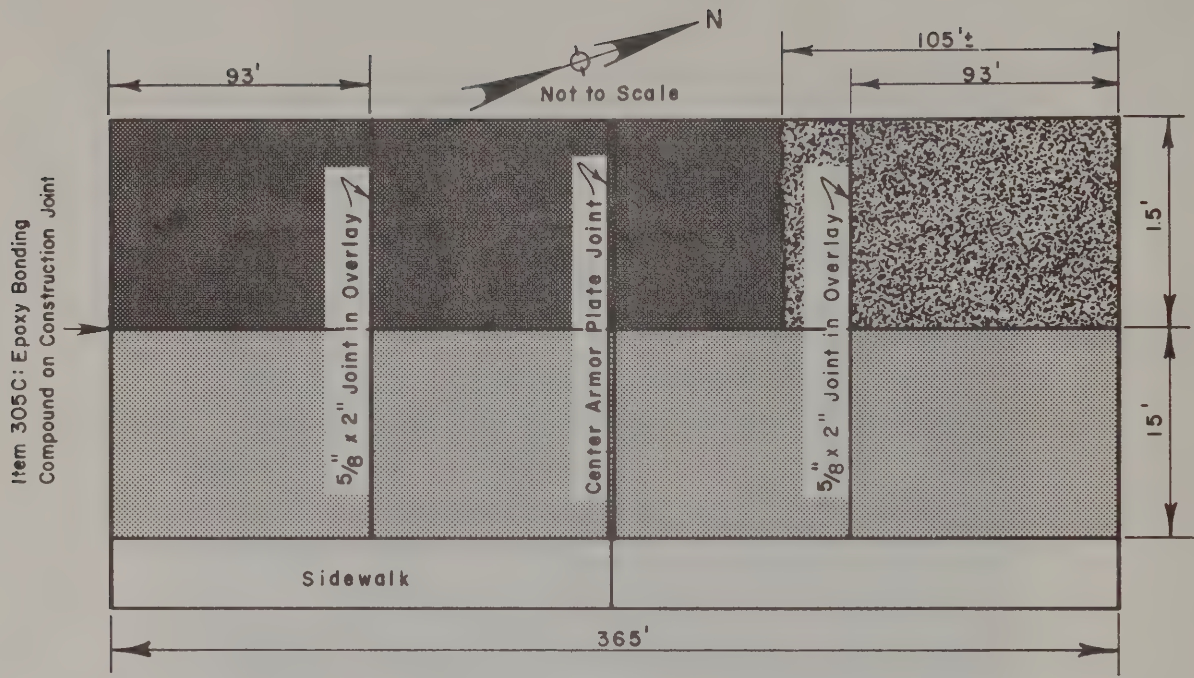
Figure 4. Fiber loading table with 8-yd^3 transit-mix truck (top) and grating placed over truck hopper (bottom) to prevent fiber balling (note pencil vibrator).

Figure 5. Balls of fibers removed from the deck.

mix design worked well on October 24 and 25. Also, the northbound lane was inspected during southbound placement and no cracks were found. The fiber content reduction was necessary as the batch plant was running low on fibers. The rejected loads had used all the producer's excess fibers.

The first truck with this mix arrived at the job at 12:25. No balls were found but the mix had high slump and air content. With one-third less fibers than the original mix, more mortar was available. This made the mix pasty or greasy and probably was responsible for the high slump and air. Consequently, the water content was also reduced. The next truck had an acceptable load with no balls and a slump and air within specification tolerances. Thereafter, the truckloads ran on the stiff side. The truck drivers were extremely hesitant to add water at the job site because of their bad experience with the previous wet loads. Since the finishers seemed to have little trouble producing a smooth surface, the stiffer loads were used.

As on the northbound lane, the southbound was brought to a smooth finish with a vibrating float and hand luting. Also, a broomed finish was produced by hand and white membrane curing compound was spread. After hardening, Burlene was placed on the overlay for protection from cold, and insulated blankets were also available. Placement of the entire overlay was completed by approximately 4:30 p.m. Workmanship was good and the fibrous concrete had a smooth surface. Table 6 gives field data and the results of strength tests on the November 15 fibrous concrete. Figure 6 shows placement of the various fibrous concrete mixes and the positions of joints sawed in the overlay. The latter were 5/8-in. wide by 2-in. deep and were sealed with 1¼-in. preformed neoprene extrusions.



Mix 1 = Original 8-bag specification mix, containing 150 lb of fiber/yd^3

Mix 2 = 6-1/4-bag mix recommended October 1, containing 100 lb of fiber/yd^3

Mix 3 = Original 8-bag specification mix, with fiber content reduced to 100 lb/yd^3

Figure 6. Deck layout.

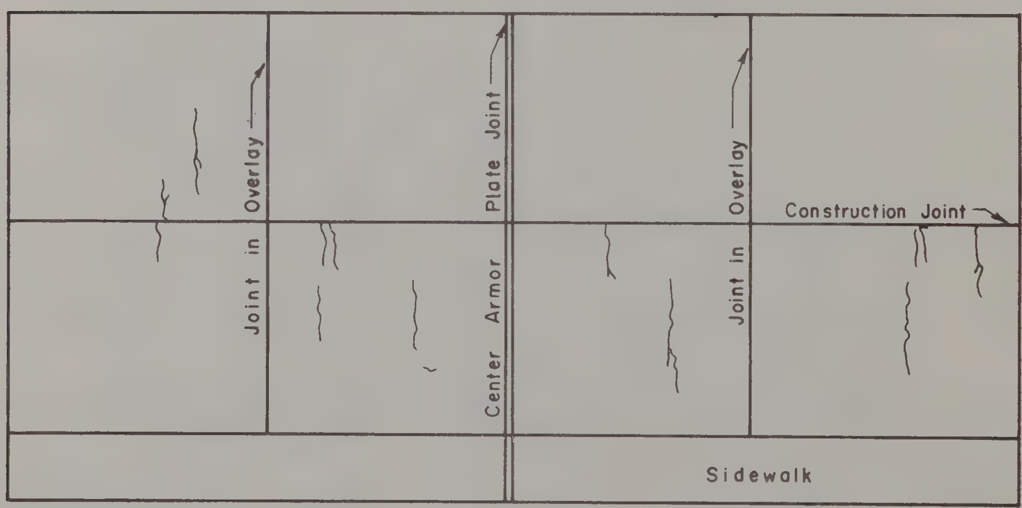


Figure 7. Crack locations.

IV. POST-CONSTRUCTION INSPECTIONS

Inspections were initially scheduled at 6-month intervals. The first was conducted on January 7, 1974, less than one month after the structure was completely reopened to traffic. No cracks were then apparent anywhere in the overlay. Surface fibers in the northbound lane (the first placed) showed slightly more rusting than those in the southbound, but there was no substantial staining of the overlay. Only one small spall (1-in. diam and 1/4-in. deep) was found. Also, several boot prints were visible in one area of the southbound lane.

On June 18 the second inspection was conducted. This was originally scheduled for July, but occurred a few weeks early because hairline cracks were reported in the deck. They were noticed during the first week in June by the project's Engineer-In-Charge; they were tightly closed but did allow the passage of water through the deck. The Engineer-In-Charge thus ordered the contractor to make repairs. The latter attempted repairs by pouring Duralith epoxy onto and into all the cracks that could be found.

During the second inspection the deck was examined extensively. The following details were noted:

1. Not counting the crack at the construction joint between lanes, a total of 15 hairline cracks were found. Five had not been repaired. Figure 7 shows the positions of the deck cracking. Interestingly, 13 of the 15 cracks were in the northbound lane.

2. In contrast to the previous inspection, spalling was much more evident. Approximately 50 spalls were discovered, compared to only one during the January inspection. They seemed to be of two types (Fig. 8). The first could be characterized as a fiber popout -- a fiber near and approximately parallel to the surface was apparently dislodged and a small spall the shape of the fiber but slightly larger was the resulting discontinuity in the overlay surface. The second type looked like the normal small spall typical of concrete pavements, but one or more fibers were usually visible in the bottom of such a spall. Thus, fibers may also have contributed to this type of spalling. There were approximately 25 spalls of each type. Six "normal" spalls also had occurred along the joints sawed in the overlay; the sawed joint edges were not beveled and that probably accounted for these spalls.

3. Considerably more corroding or rusting of fibers was noticed during this inspection than in January, but the overlay was still not badly stained. It appeared slightly darker than the normally constructed portland cement approach slabs.

Figure 8. Spalls encountered were of two types -- fiber pop-outs (top) and normal spalls with fibers at bottom (below).

4. The broomed finish showed signs of wear, particularly in the wheelpaths. Because of this wear and two accidents on the structure during the winter, it was skid tested at 40 mph. Average skid numbers obtained on August 23, 1974, were 43.5 northbound and 46.5 southbound; skid-resistance properties of the overlay thus appear sufficient.

5. The bridge railing was spray-painted during the spring. A thin film of green paint had resulted from overspray on some areas of the deck.

OBSERVATIONS AND CONCLUSIONS

The following observations and conclusions can be drawn from the Materials Bureau's work with fibrous concrete:

1. In laboratory testing, fibrous concrete performed less well than expected. The outer coat of drawing compound on the fibers used in the test program may have been responsible. Loaded to ultimate failure, fibrous concrete failed when the fibers debonded from the concrete mortar matrix. The excess compound most probably contributed to and/or actually promoted debonding and premature failures thus occurred.

2. Ultimate strengths determined from field samples of fibrous concrete were also less than expected. The field concrete contained many fibers coated with drawing compound but 25 to 50 percent of the fibers apparently had none.

3. The mix recommended by Battelle on October 1 to overcome shrinkage cracking problems apparently tended to ball. Some balling occurred during trial batching and massive balling during construction. Upon discontinuing use of this mix, balling problems ceased, but at the same time tighter controls were instituted on truck mixing revolutions. Thus, the balling problem could easily have been due to slow drum revolution during fiber introduction at the batch plant.

4. The batching operation for fibrous concrete poses problems, and needs improvement and refinement. At its best, batching requires more time and effort for fibrous concrete than normal concrete. At its worst, it can produce an unusable material.

5. No major problems developed during placement and finishing on this deck. Construction techniques for fibrous concrete are virtually identical to those for normal portland cement concrete.

6. The first year's performance of the overlay was less than expected. Fifteen cracks were discovered during the second post-construction inspection (6 months in service). These were probably shrinkage cracks that had not opened enough to be detected during the earlier inspection. Some 13 of the 15 cracks occurred in the northbound lane, constructed with the specification mix design (Mix 1), which evidently did have a tendency toward developing shrinkage cracks as noted by Battelle. Additionally, Mix 1 had a high water content, a high cement content, and a small coarse aggregate size. These three items generally increase the shrinking tendencies of concrete mixtures. As of June

1974, the mix recommended by Battelle on October 1 to overcome shrinkage problems (Mix 2) had not developed any cracking; this mix had reduced water, cement, and fiber contents. The original mix with reduced fiber and water content (Mix 3) had only two cracks. Water, cement, and fiber contents of the mixes as placed in the overlay were as follows:

Mix	Average Water Content, lb/yd^3	Cement Content, lb/yd^3	Fiber Content lb/yd^3
1	415	752	150
2	366	600	100
3	338	752	100

Most fibrous concretes in use today require a small coarse aggregate size, probably rendering them slightly susceptible to shrinkage problems. During this limited experiment, combining small coarse aggregate with high water and/or cement contents appeared to encourage shrinkage cracks.

7. Overlay performance with regard to spalling was also poorer than expected. Fifty small spalls of two types were discovered in this overlay. The first -- fiber popouts -- resulted when a fiber near and approximately parallel to the surface popped out, leaving a small spall the shape of a fiber but slightly larger. The second has the appearance of the normal small spall common on concrete pavements, but fibers were usually visible in its bottom. Thus, fibers may also have contributed to this type of spalling. Spalling of either type may result from corrosion of the fibers. Since the corrosion product of steel is five to fifteen times more voluminous than the steel itself, the resulting expansion can create tensile stresses on the surface of the fibrous concrete that may lead to spalling. Slight rust staining of the deck is evidence that the steel fibers are in fact corroding.

8. Performance of fibrous concrete in relation to wear has been acceptable to date. Although wearing of the broom finish was noted during the second inspection, skid resistance has remained sufficient for safe driving.

9. Economically, fibrous concrete is expensive on a first-cost basis. The price for finished in-place fibrous concrete on this project was \$325/yd^3. According to 1973 weighted average bid prices, a similar overlay using normal Class A concrete and reinforcing mesh would cost \$183/yd^3. The fibrous concrete work was experimental, however, and this may have increased its price. Nevertheless, raw materials for fibrous concrete are more expensive than those for normal portland cement concrete and considerably more time and effort is required in batching.

In summary, during this admittedly limited experimental project, fibrous concrete performance in the laboratory and the field has been disappointing. Nevertheless, field performance of the fibrous concrete overlay may show a relative improvement over the long term. The Materials Bureau, therefore, will continue the post-construction inspections, but will not recommend conducting additional experimental work with fibrous concrete until its batching and shrinkage problems are definitely overcome.

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BIBLIOGRAPHY

Design and Control of Concrete Mixtures. Eleventh edition. Skokie, Ill.: Portland Cement Association, 1968, pp. 42-53, 83-86.

Gramling, W. L., and Nichols, T. H. "Steel-Fiber-Reinforced Concrete." Special Report 148, Transportation Research Board, 1974, pp. 160-65.

Gray, B. H., Williamson, G. R., and Batson, G. B. (comps.). Fibrous Concrete: Construction Material for the Seventies. Conference Proceedings M-28, U.S. Army Construction Engineering Research Laboratory, 1972. Fourteen papers presented at Champaign, Ill., May 1-3, 1972, distributed by the National Technical Information Service under Accession No. AD 756384.

Lankard, D. R., and Walker, A. J. "Pavement Applications for Steel Fibrous Concrete." A paper presented at the ASCE Transportation Engineering Specialty Conference, Montreal, Canada, July 15-19, 1974, available as Preprint MTL-64 from the Engineering Institute of Canada.

Podolny, Walter, Jr. (comp.). Highway Focus, Vol. 4, No. 3 (October 1972). Seven papers in a special issue of a magazine published by the Federal Highway Administration, U.S. Department of Transportation.

APPENDIX

SPECIFICATIONS FOR CONTRACT RCR 73-85

A. Item 47F: Concrete Pavement -- Steel-Fiber-Reinforced
B. Item 355LS: Crack Sealing -- Structural Slab

A. Item 47F: Concrete Pavement -- Steel-Fiber-Reinforced

1. Description

Under this item, the contractor shall construct a steel-fiber-reinforced portland cement concrete bridge deck overlay pavement and sawed contraction joints as shown in the plans and described in this specification. The fibrous overlay shall be placed on the existing structural slab which has had the existing overlay removed and is free of all loose aggregate and foreign material.

Steel-fiber-reinforced portland cement concrete shall be treated as an experimental material on this contract. This will require extensive testing by the Department, in addition to the normal quality control testing. It will also require the cooperation of the contractor and state in developing acceptable methods of mixing, placing, and finishing the material. At least one trial batch (one cubic yard minimum) shall be produced approximately one month prior to the placement of the overlay. It is expected that the experimentation and testing will cause an increase in the amount of labor, equipment, and time required for the project. The contractor shall consider the above information in arriving at his bid price for this item.

2. Materials

The steel-fiber-reinforced portland cement concrete installed under this item shall comply with the requirements given under Section 7, "Portland Cement Concrete," and its subdivision, "Structural Concrete," of the New York State Department of Public Works Specifications of January 2, 1962, as modified by the addenda, subject to the following exceptions:

The steel-fiber-reinforced portland cement concrete shall consist of a homogeneous mixture of cement, fine aggregates, coarse aggregates, certain steel fibers randomly oriented and dispersed throughout the mix, water, and admixtures when required.

The coarse aggregates shall conform to the requirements of Size 1 of Item M4, "Coarse Aggregates," as given under Section 6, "Materials of Construction," of the above-noted specifications.

The fine aggregates shall conform to the requirements of Types A, B, or C of Item M3, "Fine Aggregates," as given under Section 6, "Materials of Construction," of the above-noted specifications.

The carbon steel fibers shall conform to the following tensile requirements:

Minimum tensile strength, psi	80,000
Minimum yield strength,	70,000
Minimum reduction of area, percent	30

The dimensions of the carbon steel fibers shall be 0.025 in. ± 0.001 in. in diameter by 1½ in. ± ¼ in. in length.

A suggested mix design for a cubic yard of steel-fiber-reinforced portland cement concrete is as follows:

Portland cement, bags	8 (752 lb)
Fine aggregate (saturated surface dry), lb	1870
Coarse aggregate (saturated surface dry), lb	610
Steel fibers (2½ by 0.025 in.), lb	150
Water, lb	368
Air, percent	7 ± 2
Slump, in.	3 to 5

The contractor may submit an alternate mix design to the Deputy Chief Engineer (Structures) for approval. It must be submitted a minimum of sixty days prior to the placing of any steel-fiber-reinforced concrete pavement.

Whether an alternate mix design is used, or the suggested mix design is used, the Materials Bureau shall determine, form the trial batch, whether the mix requires altering and further test batching.

In addition to meeting the requirements of "Proportioning Equipment" of Section 7, "Portland Cement Concrete," of the New York State Department of Public Works Specifications, the contractor shall develop an acceptable method to introduce the fibers into the concrete, together with the equipment necessary to accomplish this. The contractor's fiber intoduction method and equipment shall be subject to the approval of the Materials Bureau.

If truck mixers are used, the charging and mixing procedures shall be subject to the approval of the Materials Bureau.

The seal used in the contraction joint shall conform to Materials Specification M38PF.

3. Construction Details

Steel-fiber-reinforced cement concrete shall be placed in accordance with the New York State Department of Public Works Specifications of January 2, 1962, Part II, Section 7, "Portland Cement Concrete," with the following exceptions:

All equipment for mixing, transporting, and placing the fibrous concrete shall be subject to the approval of the Materials Bureau.

The existing slab shall be moistened with a fine spray of water prior to the placement of the overlay concrete. The spraying operation shall immediately precede the paving operation so that the slab will be damp during the paving operation.

Wherever the requirements of "Structural Concrete" and this specification are in direct conflict, the terms of this specification shall apply.

The contraction joints shall be sawed in accordance with Standard Sheet No. 70-48F, the plans, and this specification. The contraction joints shall be sealed in accordance with this specification, the plans, and New York State Department of Public Works Specifications of January 2, 1962, Part II, Section 7, "Pavement Concrete," with current additions and modifications.

B. Item 355LS: Crack Sealing -- Structural Slab

1. Description

The work shall consist of the following operations:

Scoring, or otherwise enlarging the crack at the surface of the structural slab so that a V-shaped notch or groove is formed that is centered over the crack to be sealed. The groove is to be 3/4-in. deep, having the two side of the V as nearly perpendicular to one another as possible.

Filling of the cracks with the appropriate joint-sealing materials in the manner shown on the contract plans and in accordance with the terms of the specification.

2. Materials

Sealant may be either of the following two types:

a. Hot-Poured Rubber-Asphalt

This material shall be a blend of three parts asphalt to one part rubber.

The rubber shall be devulcanized and shall be in powdered form.

The asphalt shall be of a petroleum type and shall have the following physical properties:

Penetration at 77 F, 100 g, 5 sec	85-100
Penetration Ratio (39.2 F/77F x 100)	30+
Percent loss at 325 F (max.)	1.0
Percent penetration of residue (min.)	60.0
Percent solubility in CCL_4 (min.)	99.5
Flash point, deg F (min.)	347
Ductility at 77 F, cm (5 cm/min.), min.	60

b. Two-Part Polyurethane Compound

This material shall conform to the requirements of Federal Specification TT-S-00227E, and have the following physical properties:

Solids, percent	100
Color	
Part 1	Tan
Part 2	Black
Mixed	Black
Viscosity (mixed) at 77 F, cps	1 to 20,000
Work Life	
At 60 to 70 F, hr	1-3/4 to 2
At 20 to 30 F, hr	3
Tensile Strength (ASTM D 412), psi	450
Ultimate Elongation, percent	400
Hardness (Shore Durometer A)	30 to 35

Sealant will be accepted at the project site when accompanied by the manufacturer's certification that it meets the requirements of this subsection.

3. Construction Details

At least two weeks prior to the beginning of this work, the manufacturer's instructions for the placement of the sealant shall be delivered to the Engineer. If the sealant used is hot-poured rubber-asphalt, the manufacturer's instructions shall be strictly followed.

All cracks to be filled shall be scored completely before any filling operation is begun. Immediately prior to the filling operation, the notch shall be thoroughly cleaned by air-blowing or vacuum cleaning, so that a clean, dry notch is produced.

Crack filling operations may not be done in rain or mist, and any crack that has the filling operation started must be finished during the same working day throughout its full length.

4. Method of Measurement

Payment will be made for the number of linear feet of cracks filled in accordance with this specification.

5. Basis of Payment

This unit price bid shall include the cost of all labor, materials, and equipment necessary to complete the work.